# ON THE PITCH OF GALTON-WHISTLES.

By CHARLES S. MYERS, M.D.

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# ON THE PITCH OF GALTON-WHISTLES. By CHARLES S. MYERS, M.D., Gonville and Caius College.

THE original form of whistle, described by Galton[1] in 1876, consisted of a minute organ-pipe, the length of which could be varied by a solid rod moveable within the pipe by means of a micrometer-screw. With a similar pattern, made by Hawksley, of Oxford Street, London, most of the experiments referred to below have been performed. The Hawksley-Galton whistle has a bore of one millimetre. It carries an ivory scale, on which are engraved the vibration-frequencies of the notes, theoretically produced by the whistle when 2, 3, 4, etc. millimetres long. With a length of two millimetres the whistle should give a tone of about 42,000 vibrations per second!

This whistle has been graduated according to the formula $n=\frac{v}{4l}$, where $n$ is the vibration-frequency, $v$ the velocity of sound in air, $l$ the whistle pipe-length. Galton himself writes[2]; the rule that the length of a sound-wave in a whistle or other closed pipe is four times the depth of its cavity "supposes the vibrations of the air in the tube to be strictly longitudinal and ceases to apply when the depth of the tube is less than about one and a half times its diameter."

If my experiments show that this formula is inapplicable to the Hawksley pattern of Galton-whistle, it cannot *à fortiori* be employed to calculate the pitch of the German and French patterns, which have a bore of three or four millimetres, and a pipe-length diminished to 3, 2 or even 1 millimetre. Indeed to König's model, Schulze[3] has endeavoured to apply a very different formula, devised by Helmholtz for estimating the pitch of resonators with narrow openings,

$$n=\frac{a\sqrt[4]{\sigma}}{\sqrt[4]{\pi^5}\,.\,\sqrt{2S}}$$

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[1] Before a Conference in connexion with the South Kensington Loan Collection of Instruments.

[2] *Inquiries into Human Faculty and its Development*, London, 1883, p. 375.

[3] *Annal. d. Physik u. Chemie*, 68, S. 99—104, S. 869—883. 1899.

when $a$ is the velocity of sound, $\sigma$ is the area of the circular aperture, and $S$ the volume of the resonating cavity.

Of late years a Galton-whistle has been made by Edelmann[1], of Munich, on the principle of the locomotive steam-whistle. The whistle-pipe is separated from the mouthpiece, at the lower end of which the air issues from a minute annular slit. The distance or mouth-breadth (Maulweite) between the slit and the upper end of the pipe, on which the escaping air impinges, can be varied by means of a micrometer-screw. The pitch of the note is determined by the mouth-breadth as well as by the pipe-length. Each whistle (not only each whistle-length) has its optimum mouth-breadth.

With these two patterns, the Hawksley- and the Edelmann-Galton whistles, I have endeavoured to determine the pitch of the tones emitted at different lengths, and the changes in pitch produced by changes in the force of the air-blast employed. My earlier experiments were made with the Hawksley pattern, and fall into two groups.

In the first series, I kept the wind-pressure constant, slowly shortening the pipe-length until I had reached my upper limit of hearing. I then made various changes in the wind-pressure and at each change determined my limit afresh. It was conceivable that a rise of wind-pressure, if it increased the loudness of the tones, might render audible a tone inaudible at a lower pressure. It was likewise conceivable that the same cause might raise the pitch of the tone so that it no longer fell within the limit of hearing.

The results displayed in the following table have for the most part been verified by subsequent repetitions. They show how irregularly the pitch changes when the pipe-length is gradually shortened, the wind-pressure being kept constant.

In a second series of experiments the whistle-length was kept constant and the variation in pitch was noted which a change of pressure produced. The vibration-numbers were determined either by the method of sensitive flames or by that of Kundt's dust-figures. The latter I found to be inapplicable with low wind-pressure, as the disturbance is not intense enough to throw the dust into vibration. The frequent hearing of these whistle-tones produced in me at night subjective sensations so high in pitch and so disturbing in intensity, that I had to abandon my original plan of pursuing the determination of their pitch in a more thoroughly systematic manner.

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[1] *Zeitschr. f. Ohrenhlk.* 36, S. 330—345. 1900; *Annal. d. Phys. u. Chem.* 2, S. 469—482. 1900, 4te Folge.

| Pressure in mm. of water | Length of whistle in mm. | Character, etc. of note |
|---|---|---|
| 30 | 16·00 | A good clear note |
| | 14·00 | It begins to quiver |
| | 10·00 | It is *lost* entirely |
| | 8·00 | A very quivering note reappears |
| | 6·50 | A clear high note |
| | 4·75 | It begins to quiver |
| | 4·50 and onwards | It is lost |
| 60 | 16·00 | Silence |
| | 15·00 | A very faint quivering note |
| | 13·50 | A good clear note |
| | 6·25 | It begins to quiver |
| | 5·25 | *It is lost* |
| | 5·00 | Suddenly it becomes *far higher* of a different character |
| | 4·90 | It quivers |
| | 4·25 | The quivering drowns its clearness |
| | 3·75 and onwards | No tone |
| 90 | 16·00 | A quivering note |
| | 15·00 | A good clear note |
| | 5·00 | The clearness is retained |
| | 4·00 | A sudden change with an obviously *lower* note |
| | 3·75 and onwards | It is lost |
| 120 | 16·00 | Very quivering note |
| | 13·00 | Note becomes very faint |
| | 10·25 | Note becomes clearer and more continuous |
| | 10·00 | A piercing clear note |
| | 3·75 and onwards | The note suddenly ceases |
| 180 | 16·00 | A quivering note |
| | 11·50 | A clear high note |
| | 7·25 | It is obscured in the blast of air |
| | 7·00 | It is clear and far higher |
| | 4·50 | Note is very faint |
| | 4·25 and onwards | No note |
| 250 | 16·00 | High note |
| | 15·00 | It begins to quiver |
| | 14·00 | *No note* |
| | 12·50 | A quivering note (? lower than at 16) |
| | 11·50 | A clear high note |
| | 4·75 | Note becomes feeble |
| | 4·50 and onwards | No note |
| 350 | 16·00 | No note |
| | 10·25 | A quivering note |
| | 10·00 | A high clear note |
| | 6·00 | It is somewhat obscure |
| | 4·75 | The note is feeble |
| | 4·50 and onwards | No note |
| 500 | 16·00 | No note |
| | 7·50 | A high clear note enters |
| | 5·00 | Note becomes very piercing |
| | 4·50 and onwards | No note |
| 700 | 16·00 | No note |
| | 6·25 | A high note enters |
| | 4·50 and onwards | No note |

The sensitive flame was produced from a tube of glass drawn out to a fine point. The gas was admitted to it from a large bag, which was subjected to a sufficient pressure by means of adjustable weights. The sound-waves, after passing the flame, were reflected to it by a screen moveable along a carefully graduated optical bench. The mean of the distances from each other of a number of points on the bench was taken where the disturbances of the flame produced by the waves were at their maximum (wave-loops) or at their minimum (wave-nodes).

The dust-figures were produced after the method described in detail by Schwendt[1] and Edelmann[2]. The glass tubes, containing dried lycopodium dust, varied in diameter down to 1·5 mm. and in length down to 20 mm. On two or three occasions, when the pressure was very high, I obtained twice the number of half wave-lengths I had expected, owing to the accompaniment of overtones. I cannot, however, see that the variations in pitch produced by changing the wind-pressure are attributable to overtones in the case of the Hawksley-Galton whistle, although with the Edelmann-Galton pattern this is the probable cause.

I made no allowance for the reduction of the velocity of sound owing to the narrow calibre of the tubes. The alteration so caused, according to the formulæ of Kirchhoff and Kayser, appears to be small enough to be negligible beside the possible experimental errors.

The velocity of sound was calculated according to the formula $v = 330{,}700 \sqrt{1 + 0{\cdot}00367t}$, $t$ being the temperature of the air. In the sensitive flame experiments ($t = 20°$ C.), $v = 342{,}600$ mm. per sec. nearly: in the dust-figure experiments ($t = 16{\cdot}6°$ C.), $v = 340{,}400$ mm. per sec. nearly.

A weighted gas-bag was found to be serviceable only for transmitting air at low pressure. To give pressures beyond 50 mm. of water, the air was driven by the force of tap-water from two large communicating bottles through a calcium chloride-tube to a T-shaped glass coupling, of which one arm led to the whistle, the other to a U-shaped glass manometer[3]. No correction was made for the dampness of the air.

Whether or not these variations in pitch according to the pressure used depend on the presence of overtones, that they must have an important bearing on the determination of the upper limit of hearing is very clear. When air is admitted into the whistle there occur two periods of very low pressure,—first, before the pressure in the conducting apparatus and instrument has reached the desired maximum, and secondly, when after shutting off the air the pressure is diminishing to zero. During these two periods sounds of lower pitch are generated than during the middle period. Consequently, near the upper limit, the subject may be expected to hear a note just when the wind is being admitted into

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[1] *Arch. f. d. ges. Physiol.* 75, S. 346. 1899.

[2] *loc. cit.*

[3] My thanks are due to Professor J. J. Thomson and to Mr T. B. Wood for permission to use the necessary apparatus in their respective laboratories, and to Mr J. W. Capstick for help in my earlier objective determinations of vibration-frequencies.

| Hawksley-Galton whistle-length mm. | Pressure in mm. of water | Pitch of tone in vibr. per sec. | Remarks |
|---|---|---|---|
| 13 | 20 | — | A mere quivering |
| | 22 | — | A note rising in pitch with greater pressure |
| | 84 | 5,748 | — |
| | 120 | — | The note quivers |
| | 135 and onwards | — | No note |
| 9 | 20 | — | A quivering high note |
| | 22 | — | A clear high note |
| | 24 | — | A quivering lower note |
| | 28 | — | A clear note rising in pitch |
| | 30 | 6,118 | — |
| | 84 | 8,118 | — |
| | 460 and onwards | — | No note |
| 8 | 20 | — | A trace of high note |
| | 24 | — | A far lower note |
| | 28 | — | The note quivers |
| | 30 | — | The note is suddenly lowered (?), rising |
| | 80 (?) | 8,830 | — |
| | 515 and onwards | — | No note |
| 7 | 22 | — | A quivering high note |
| | 24 | — | A clear high note |
| | 28 | — | A lower note |
| | 40 | — | A high note suddenly appears, rising thence |
| | 700 | — | A note still faintly audible |
| 6 | 20 | — | A low chirp |
| | 24 | — | A quivering high note |
| | 28 | — | A clear high note |
| | 36 | — | A lower note suddenly appears |
| | 48 | 7,448 | — |
| | 50 | — | A high note appears, rising thence |
| | 950 | — | A note still faintly audible |
| 5 | 28 | — | A quivering note |
| | 32 | 12,784 | A sudden change to a higher note |
| | 48 | — | The note quivers |
| | 50 | 9,464 | A lower note enters |
| | 64 | — | A higher note enters, rising in pitch |
| | 400 | 13,704 | The note audible here and for far higher pressures |
| 4·50 | 32 | — | A quivering |
| | 34 | — | A low note |
| | 36 | — | A far higher note |
| | 50 | — | No note |
| | 60 | — | A new (? lower) note appears |
| | 76 | — | Another note suddenly appears, rising thence |
| | 400 | — | Very faint, if present |
| 4 | 30 | — | A quivering |
| | 34 | — | A clear low note |
| | 40 | 15,159 | A higher note enters |
| | 46 | — | No note |
| | 66 | — | A fresh quivering |
| | 70 | 9,361 | A lower note enters |
| | 92 | 11,896 | A sudden change to higher note, rising thence |
| | 230 and onwards | ? | No note |
| 3·5 | 38 | — | A feeble clear note |
| | 40 | — | It quivers |
| | 44 | — | No note |
| | 86 | — | A quivering |
| | 114 | — | A new note enters |
| | 200 and onwards | — | No note |
| 3·25 | 44 | — | A trace of quivering note |
| | 46 | — | Note lost |
| | 106 | — | Again a quivering |
| | 126 | — | A new note enters |
| | 150 and onwards | — | No note |
| 3·00 | 36 | — | A feeble note |
| | 40 | 18,419 | — |
| | 44 | — | It quivers |
| | 64 | — | No note |
| | 115 | — | A fresh quivering |
| | 130 | 19,033 | A note enters |
| | 150 and onwards | — | No note |
| | ? | 24,812 | (Blown with rubber-ball) |
| 2·75 | 44 | — | A quivering note |
| | 56 | 19,033 | The note is heard clearly |
| | 62 and onwards | — | No note |
| 2·5 | 50 | — | A quivering note |
| | 58 | 19,466 | The note is heard clearly |
| | 66 and onwards | — | No note |
| | 800 | 22,540 | — |
| 2·25 | 58 | — | A quivering note |
| | 68 | 20,639 | The note is heard clearly |
| | 72 and onwards | — | No note |
| | 800 | 22,840 | — |
| 2·125 | 72 | 23,466 | No audible note |
| 2·00 | 68 | 25,191 | No audible note |
| | ? | 27,629 | (Blown with rubber-ball) |
| 1·75 | 84 | 25,955 | No audible note |
| | 136 | 28,082 | — |
| | ? | 30,050 | (Blown with rubber-ball) |

the whistle, and to hear it again immediately after the wind has been shut off from the whistle.

I find this *universally* to be the case. It is, however, open to doubt how far the inaudibility during the middle period is due to the above cause and how far it is due to the masking effect of the wind-blast.

Now the whistle-tones that have hitherto been subjected to objective examination have been generally those produced by exceedingly high wind-pressures, while the tones that have been actually heard by the subject at that whistle-length will in all likelihood have differed considerably from the former both in pitch and in intensity.

An example will make this clearer. I set myself to determine the highest tone audible to a friend whose threshold is exceptionally low. When I compressed the bulb with moderate force, his limit was reached at a (Hawksley-Galton) whistle-length of 13 mm., but when I compressed it gently, a note could be heard up to a pipe-length of 9·5 mm. Now the whistle, 13 mm. long, emits a note of 5907 vibr. per sec. at a wind-pressure equal to 80 mm. of water. Approximately the same note is produced with a pipe-length of 9 mm., at a wind-pressure of 30 mm.: while the same pipe-length (9 mm.) with the first-named pressure (80 mm.) yields a note of 7858 vibr. per sec.

Similar results, of course far less marked, are obtainable in the case of subjects with normal range of hearing. The whistle can always be shortened until a point is reached at which the note can be heard only at the beginning and at the end of the blast.

It might be thought that the use of a rubber-ball would have been generally condemned for blowing the Galton-whistle. Stumpf and Meyer[1], indeed, urge that with a rubber-ball "not merely is the note too short but it varies considerably in pitch during its short duration, as is recognized by the sudden rise in difference-tone." On theother hand, Edelmann prefers the blast from the ball, as being freer from accompanying noises and, owing to the brief duration of the note, as causing less fatigue than other means of blowing the whistle.

The advantage of a water-driven air-blast lies in the delicacy with which the pressure may be adjusted. But with it, no less than with the blast produced from the rubber-ball, lower tones are unavoidably emitted by the whistle, when the wind is first admitted, or when finally it is shut off.

Compression of the rubber-ball produces air-pressures which are so suddenly and momentarily developed that a water- or mercury-manometer cannot be used to measure them. Even when using glycerine in the manometer (as a more viscid fluid than mercury or water), I found it impossible to measure the pressure. A fair proof of its magnitude, however, is afforded by the experiments of Schulze with the König- and Edelmann-Galton whistles. Pressures of 240 and 550 mm. of water respectively gave lower tones with these two forms of whistle than were given by pressure of the rubber-ball at the same whistle-lengths.

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[1] *Annal. d. Phys. u. Chem.* 61, S. 773. 1897.

Edelmann sends with each of his whistles a paper which gives the certified pitch of the notes, emitted at definite lengths of whistle and breadths of aperture, and determined by curves derived from earlier estimations by the method of Kundt's dust-figures. However, he neglects throughout to mention the wind-pressure at which these vibration-numbers were obtained. Indeed he urges that his whistle is superior to other forms in being comparatively unaffected by changes in pressure.

I cannot confirm this claim. Using his latest pattern of whistle with a pipe-length of 1·3 mm., and a mouth-breadth of 0·8 mm., I can produce no sound until a pressure equal to 30 mm. of water is reached. Then a faint, quivering note is emitted which at 35 mm. pressure becomes a clear note. With further increase in pressure the tone *obviously rises in pitch*, until at 140 mm. pressure it *disappears.*

According to Edelmann, the tone emitted from his whistle at this pipe-length (1·3 mm.) should be for all pressures about $a^7$, 28,000 vibr. per sec. I find that at

| | | | | | | |
|---|---|---|---|---|---|---|
| 36 | mm. | pressure | the | vibration-frequency | is | 5,673 |
| 109 | „ | „ | „ | „ | „ | 10,942 |
| 680 | „ | „ | „ | „ | „ | 23,315 |
| 800 | „ | „ | „ | „ | „ | 28,332 |

The pitch-changes are almost certainly due to the production of overtones in this pattern of Galton-whistle.

To take a further example, Edelmann certifies the note emitted from his whistle, at length of 1·44 mm. and at a mouth-breadth of 0·8 mm., to be $g\sharp^7$, 27,000 vibr. per sec., whereas I find that at

| | | | | | | |
|---|---|---|---|---|---|---|
| 140 | mm. | pressure | the | vibration-frequency | is | 12,157 |
| 200 | „ | „ | „ | „ | „ | 18,912 |

Further increase of pressure in certain cases produces little or no change in pitch. Thus for a pipe-length of 4·43 mm. at

300 mm. pressure the vibration-frequency is 13,508
325 „ „ „ „ „ 13,616
550 „ „ „ „ „ 14,066

Edelmann gives the vibration-frequency as 13,920. No note can be heard at this pipe-length when the pressure falls below 100 mm.

Edelmann believes that his whistle can produce an audible tone with the vibration-frequency of 50,000. I endeavoured to test this claim by a series of experiments. The following questions were involved in this inquiry. (1) Are such vibrations really present? (2) Is a tone audible during the attempt to produce such vibrations? (3) Are tones of lower pitch produced, *ceteris paribus*, under conditions of lower wind-pressure? (4) Does the tone (2), if heard, correspond to the high vibration-frequency which is objectively determined, or does it appear only at the moments of admitting and of shutting off the wind-pressure, corresponding therefore in all likelihood to the tones of (3)?

After many attempts I have not succeeded in producing such minute wave-lengths even in short tubes of very fine calibre, and with a pressure of about 800 mm. of water. I have, however, several times produced them, using a powerful pressure on the rubber-bulb, and have deduced a vibration-frequency of 46,630. When the whistle is blown at this length of pipe with extreme gentleness, a note may often be heard; but it is so faint as to be unmeasurable by any known method. With a forcible blast neither I nor various friends could hear any note.

Having regard to the experiments before mentioned made with greater length of whistle, there appears to me little danger in arguing by analogy that really a note of 50,000 vibr. per sec. is inaudible, and that what is heard is a note of lower pitch (and of lower intensity) produced by a lower pressure at the entry and at the close of the air-blast.

## Conclusions.

The result of these experiments is to show *inter alia* that:

(1) In all varieties of Galton-whistle the pitch of the tones varies with the pressure of wind employed, the alterations of pitch through changes of pressure being usually greatest when the pressure is relatively low.

(2) Increase of wind-pressure occasionally produces a sudden lowering of the pitch.

(3) In certain cases the pressure can be so adjusted as to give no audible sound, while a tone can yet be heard if the pressure is in the least degree increased above or diminished below that point.

(4) A point is reached near the upper limit of hearing where a sound is only heard when the blast enters or is leaving the whistle. These are moments when the pressure is low and tones of lower vibration-frequency are emitted.

(5) To estimate the pitch of the highest audible tone, either the wind-pressure must be taken into account at the moment both of the physiological and of the physical determinations, or the lowest obtainable tone emitted by the whistle with a given pipe-length (at relatively low wind-pressures) must be assumed to be the tone actually heard by the subject at that pipe-length. [It is clearly hopeless to rely on the subject's statement that he hears a sound only at the beginning or end of the blast.]

(6) A whistle-tone of 50,000 vibrations per second is inaudible. The highest audible tone from the Hawksley-Galton whistle for young adults is one of from 20,000 to 25,000 vibrations per second, as is shown by experiments in Torres Straits, Egypt and Scotland[1], which will appear in a forthcoming number of the *Reports of the Cambridge Anthropological Expedition to Torres Straits* (University Press, Cambridge).

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[1] Cf. *Arch. of Otology*, xxxi. pp. 284, 285. 1902.